MECHANICAL CHARACTERISTICS OF THE VALVE-AORTA UNIT IN HUMANS


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The successful use of heart valve prostheses has enhanced interest in the mechanics of natural valves in animals and humans. The aortic valve has been the subject of greatest study due to the wide use of the aortic valve in allo- and hetero-prostheses [1, 2]. The study of the mechanics of the aortic valve also is contributing to the design of an optimal artificial lobed tricuspid valve prosthesis [3]. Interest in this subject has traditionally centered on the geometry, properties, and stress—strain state of the semilunar cusps [4-6]. However, the cusps are not the only elements functioning to shut the aortic valve. Swanson [7] has indicated the important role of the aortic Valsalva sinuses in providing reliability and optimal hemodynamics for valve operation. We have found the presence of an elastic housing in a valve—aorta heterounit [8, 9] consisting of elements which are significantly more rigid than the Valsalva sinuses, aorta, and cusps. It is precisely the mechanical behavior of this rigid housing which determines displacements and, thus, the stress—strain state of the membranous elements of the aortic valve [8, 9]. Determination of the actual mechanics of the human valve—aorta unit and of the functional features of its individual elements is possible only on the basis of their mechanical characteristics.

The experimental samples were aortic valves from the ascending and descending parts of the aorta obtained from 12 males who died as a result of mechanical trauma. The donor age was from 21 to 35 yr in order to reduce the effect of age-induced changes on the mechanical properties. The selection of the samples for mechanical testing was carried out visually with the aim of selecting samples with minimum atherosclerotic damage.

The mechanical testing was carried out under uniaxial tensile stressing for flat samples cut in the form of a spade using a special stamp. The dimensions of the working portion of the samples were \( l_0 = 17 \text{ mm} \) and \( b_0 = 2 \text{ mm} \). The cut directions for samples from different elements of the valve—aorta unit and the method of tensile testing were described in our previous work [9, 10]. The amount and designation of the samples tested are given in Table 1.

Using the experimental diagrams for the dependence of \( P \) on \( \Delta l \), we calculated the ultimate stress \( \sigma_{\text{max}} \) and deformativity margin:

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\sigma_{\text{max}} = \frac{P}{F_0} ; \quad \varepsilon_{\text{max}} = -\frac{\Delta l}{l_0} ,
\]
where $P_s$ is the ultimate stress determined from the experimental diagram as the stress corresponding to the first loss of sample continuity (the sharp drop in the experimental diagram in Fig. 1), $F_0$ is the initial cross-sectional area of the sample, $\Delta l_s$ is the elongation of the sample corresponding to the first drop in stress in the experimental diagram, i.e., corresponding to $P_s$, and $l_0$ is the initial length of the working section of the sample.

The use of stress $P_s$ corresponding to the first loss of sample continuity as a measure of material strength is a factor of the decomposition behavior of vascular walls. The composite material of vascular walls [11, 12] has the feature of maintaining a load which sometimes exceeds the load when initial damage is noted. Figure 1 shows an example of such a diagram where the stress corresponding to complete destruction is 45% greater than the stress defined as $P_s$.

The calculated values of $\sigma_{\text{max}}$ and $\epsilon_{\text{max}}$ were subjected to statistical analysis and presented in Table 1. We found a consistent invariance in the ratios of strength and deformativity of various elements of the same unit for all samples studied. Despite variations in the absolute values of $\sigma_{\text{max}}$ and $\epsilon_{\text{max}}$ of the individual features determined, their relative values were virtually constant even for valves taken from subjects with extreme values of age and other such individual features as mass, heart size, and dimensions of the aorta and valve in the group studied.

Table 2 gives the mean arbitrary strength and deformativity of the elements of the human valve—aorta unit and the coefficients relating these indices for the various elements. This table shows that the coefficients relating the deformation properties of the unit elements are most stable ($p < 0.05$), indicating that the deformative behavior of the elements of the valve—aorta unit is found in a definite proportion which does not vary from valve to valve and accounts for the coordinated deformative behavior in response to individual stress conditions.